CS 5430

Passwords, part 2

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Review: Authentication of humans

Categories:

- Something you know

  password, passphrase, PIN, answers to security questions

- Something you have

  physical key, ticket, {ATM,prox,credit} card, token

- Something you are

  fingerprint, retinal scan, hand silhouette, a pulse

Review: Password lifecycle

1. **Create:** user chooses password
2. **Store:** system stores password with user identifier
3. **Use:** user supplies password to authenticate
4. **Change/recover/reset:** user wants or needs to change password

2. PASSWORD STORAGE

Review: Salted hashed passwords

- Defend against offline guessing attacks
- Each user has:
  - username uid
  - unique salt s
  - password p
- System stores: uid, s, H(s, p)

To authenticate Hu to L:

```
1. Hu->L: uid, p
2. L: let h = stored hashed password for uid;
      let s = stored salt for uid;
      if h = H(s, p)
      then uid is authenticated
```

Review: Salt

To combine with iterated hashing, include salt in first hash:

```
z1 = H(p, s);
z2 = H(p, z1);
...
...
z1000 = H(p, z999);
output z1 XOR z2 XOR ... XOR z1000
```

this idea used in widely-deployed algorithm for deriving encryption keys from passwords...

PBKDF2

- Password-based key derivation function 2 [RFC 2898]
- **Output:** derived key k
- **Input:**
  - Password p
  - Salt s
  - Iteration count c
  - Key length len
  - Pseudorandom function PRF(m; s): "looks random" to an adversary that doesn't know the *seed* s
    - Common instantiation is HMAC, which itself is parameterized on choice of hash function
    - PRF(m; s) is HMAC(m; s), that is, seed of PRF becomes key of MAC

PBKDF2

Algorithm:

- k = T(1) || T(2) || ... || T(n)
  - enough T's to achieve desired len
  - || denotes bit concatenation
- T(i) = F(p, s, c, i)
  - F is in essence a salted iterated hash...
- F(p,s,c,i) = U(1) XOR ... XOR U(c)
  - U(1) = PRF(s, i; p)
  - U(j) = PRF(U(j-1); p)

Could use this to store passwords in addition to deriving keys from them, since F(p,s,c,1) is essentially what we agreed to store for salted and iterated-hash protected passwords

WiFi

- WiFi WPA2 uses PBKDF2
  - Derive long-term key from passphrase
  - (later derive session keys from long-term key)
- Long-term key derivation:
  - p = passphrase
  - s = ssid
  - c = 4096
  - len = 256
  - PRF = HMAC with SHA-1
    - WPA2 is from (pre-)2004
    - SHA-1 attacks didn't appear until 2005
    - Protocols live forever!

Costly hashes

- Time is no longer *the* limiting factor
  - Custom ASICs
  - GPUs
  - Parallelize across the hardware
- Relevant to cryptocurrencies

Costly hashes

- **Space** is another scarce resource
  - Idea: provide configurable tradeoff of time vs. space required to compute hash
  - Technique: large number of computationally-expensive-to-produce random elements accessed in random order
    - user computing a single hash is okay with spending a lot of time and little space
    - attacker computing billions of hashes to construct dictionary wants to minimize time but would need large space for every hash, hence hard to parallelize
- New algorithms: scrypt (2009), Argon2 (2015)

1. PASSWORD CREATION

Who creates?

- **User:** typically guessable passwords
- **System:**
  - can produce hard-to-guess passwords (e.g., random ASCII character strings)
  - but users can't remember them
- **Administrator:** reduces to one of the above

Weak passwords

Top 10 passwords in 2015: [SplashData]

1. 123456
2. password
3. 12345678
4. qwerty
5. 12345
6. 123456789
7. football
8. 1234
9. 1234567
10. baseball

21: princess, 23: solo, 25: starwars

Top 20 passwords suffice to compromise 10% of accounts [Skyhigh Networks]

Strong passwords

- How to characterize strength?
- Difficulty to brute force—"strength" or "security level"
  - Recall: if 2^X guesses required, strength is X
- Suppose passwords are L characters long from an alphabet of N characters
  - Then N^L possible passwords
  - Solve for X in 2^X = N^L
  - Get $X = L \log_2 N$
  - This X is aka entropy of password
    - Assuming every password is equally likely, X is the *Shannon entropy of the probability distribution* (cf. Information Theory)

Entropy of passwords

- NIST (2006) recommends:
  - minimum of 14 bits
  - but 30 bits more reasonable
  - How does that work out in practice...?
- Quite random passwords:
  - 8 character passwords chosen uniformly at random from 26 character alphabet
  - entropy of $8 \log_2 26 \approx 37$ bits
  - but that means 12345678 equally likely as ifhslgqz
- Less random passwords:
  - 1 word chosen at random from entire vocabulary
  - average high-school graduate: 50k word vocabulary
  - entropy of $\log_2 50\text{k} \approx 16$ bits

Entropy estimation

- **Problem:** guide users into choosing strong passwords
- Entropy estimates [NIST 2006 based on experiments by Shannon]:
  - (assuming English and use of 94 characters from keyboard)
  - 1st character: 4 bits
  - next 7 characters: 2 bits per character
  - characters 9..20: 1.5 bits per character
  - characters 21+: 1 bit per character
  - user forced to use lower & upper case and non-alphabetics: flat bonus of 6 bits
  - prohibition of passwords found in a 50k word dictionary: 0 to 6 bits, depending on password length

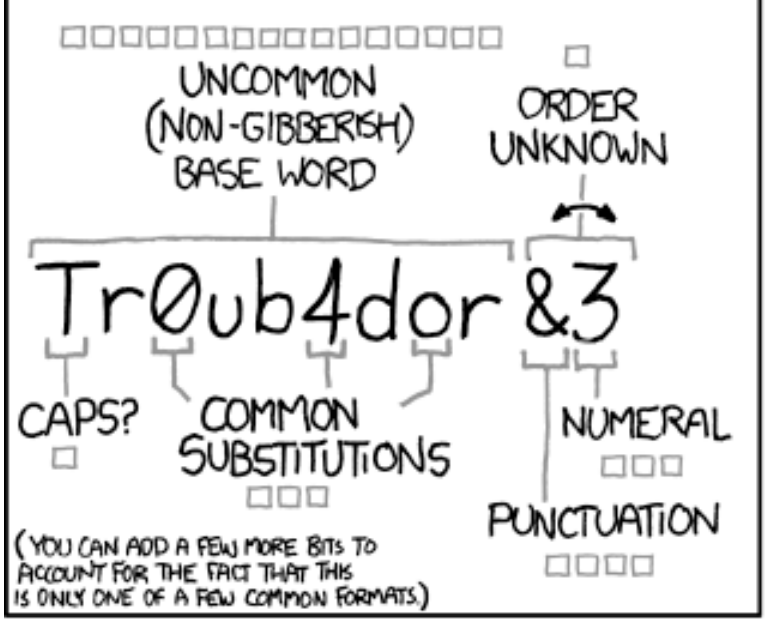
Entropy estimation

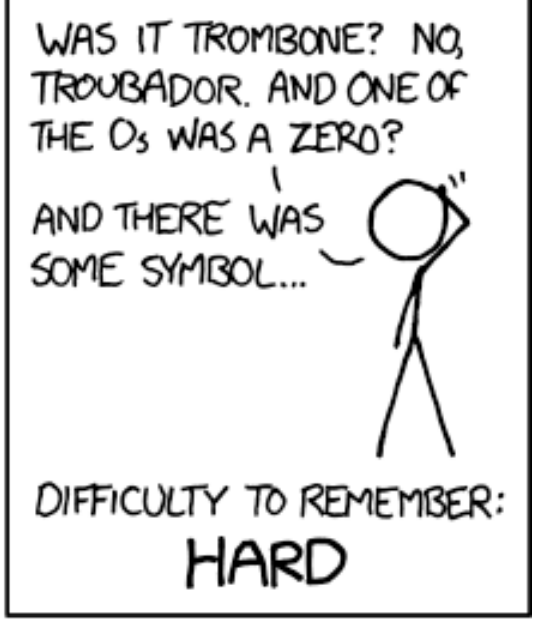
But:

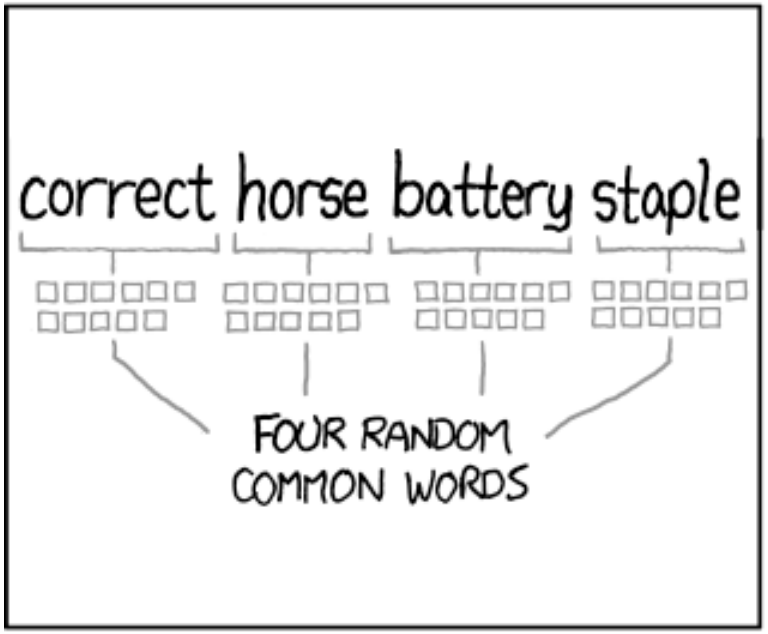
- [Weir et al. 2010] based on cracking real-world passwords conclude *"[NIST's] notion of password entropy…does not provide a valid metric for measuring the security provided by password creation policies."*
- Underlying problem: Shannon entropy not a good predictor of how quickly attackers can crack passwords

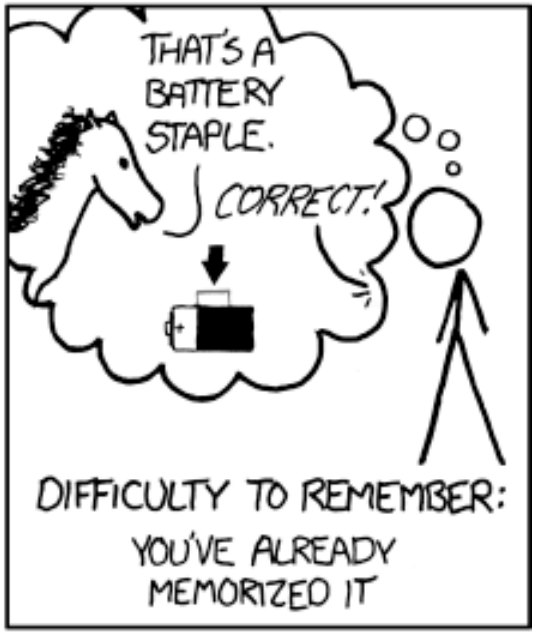
Password recipes

- Recipes: rules for composing passwords
  - e.g., must have at least one number and one punctuation symbol and one upper case letter
- Naively seems wise
- But research suggests...
  - Users who are annoyed by recipes chose weaker passwords
  - Users pick easy-to-guess passwords that minimally comply with the recipe
- Beyond recipes?
  - After user picks password, system inserts mandatory randomness into it (which users must remember): users start choosing weaker base passwords
  - Password wallets: can have random passwords, but users have to trust storage of all their passwords to a program or service
  - Longer memorable passphrases...









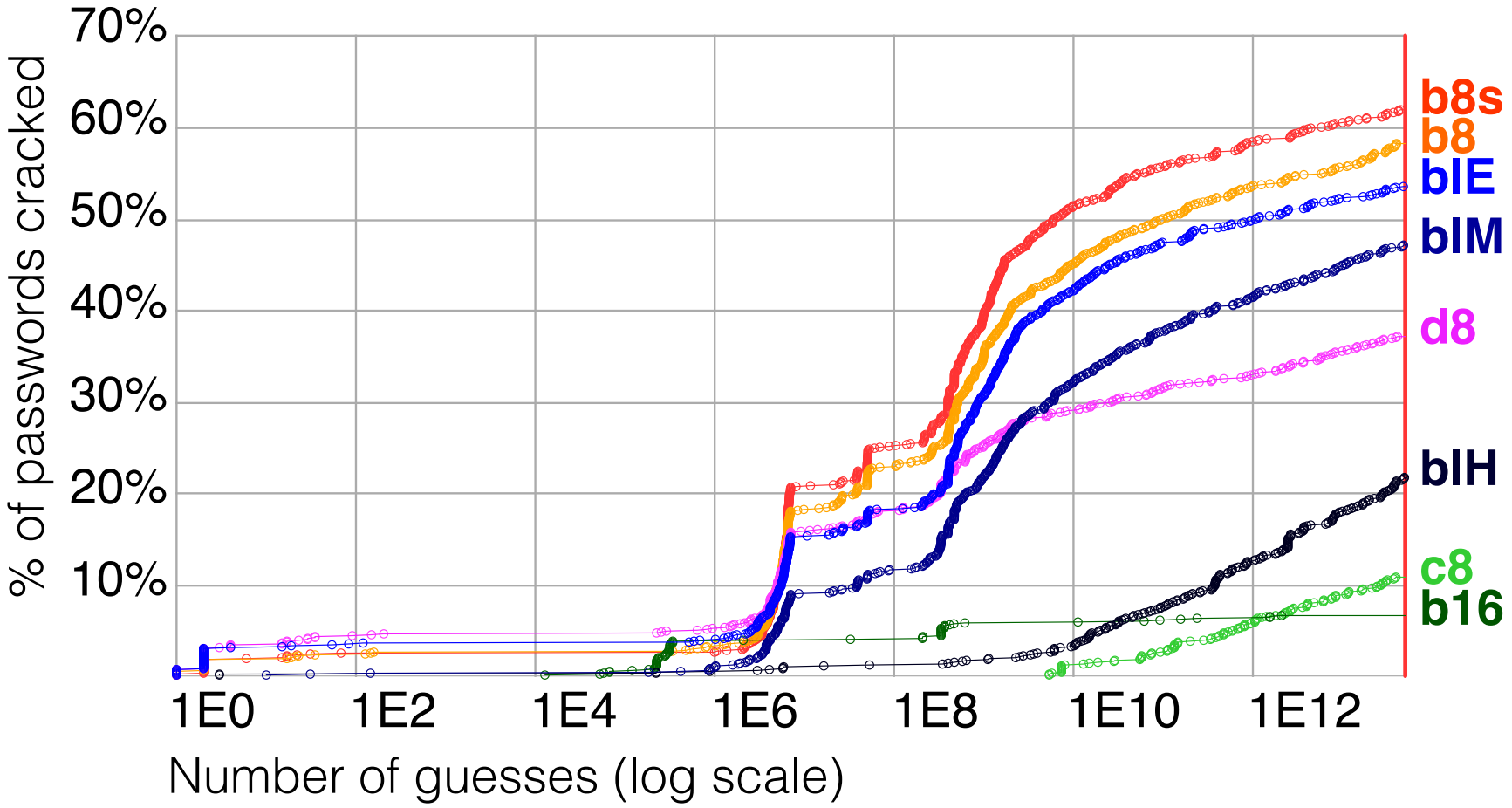
THROUGH 20 YEARS OF EFFORT, WE'VE SUCCESSFULLY TRAINED EVERYONE TO USE PASSWORDS THAT ARE HARD FOR HUMANS TO REMEMBER, BUT EASY FOR COMPUTERS TO GUESS.

Recipe comparison

[Kelley et al. 2012]

- Evaluate recipes based on
  - percentage of password cracked
  - number of guesses required to crack
  - for two state-of-the-art cracking algorithms, one of which is from [Weir et al. 2010] (same paper that invalidates Shannon entropy)
- Selected recipes:
  1. ≥ 8 characters
  2. ≥ 8 characters, no blacklisted words ...with various blacklists
  3. ≥ 8 characters, no blacklisted words from freely available 4M word common password + dictionary word list, one uppercase, lowercase, symbol, and digit ("comprehensive", c8)
  4. ≥ 16 characters ("passphrase", b16)
- Results...

Recipe comparison



Recipe comparison

- Comprehensive recipe makes it hard to crack passwords
  - So even if NIST's Shannon entropy estimates are quantitatively invalid in general, the conclusion of which recipe to recommend remains the same
- But passphrases aren't that much easier to crack
  - Threat to validity: maybe state-of-art crackers would improve to handle passphrases if people were required to use them
- And passphrases are more usable [Komanduri et al. 2011]:
  - Easier to create
  - Easier to remember

Password lifecycle

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Beyond passwords?

- Passwords are tolerated or hated by users
- Passwords are plagued by security problems
- **Can we do better?**
- Criteria: [Bonneau et al. 2012]
  - Security
  - Usability
  - Deployability

...criteria are worth studying for security in general

Security

- **Physical observation:** shoulder surfing, video recording, sound recording, thermal imaging
- **Targeted impersonation:** acquaintance or skilled investigator
- **Online guessing:** server constrains per-user rate of guess attempts
- **Offline guessing:** attacker's computational resources constrained
- **Internal observation:** attacker compromises channels, even any crypto on those channels (keyboard, SSL)
- **Leaks:** compromise at one account doesn't affect others
- **Phishing:** simulation of real server doesn't affect others
- **Theft:** physical object can't be used by another user
- **Trusted third party:** none
- **Privacy:** explicit consent, unlinkable

Usability

- **Memoryless:** humans don't have to remember secrets
- **Scalable for users:** any burden should scale to hundreds of accounts
- **Nothing to carry:** no hardware required, or at least not hardware user doesn't already always carry
- **Physically effortless:** no typing or physical motions, or at least not beyond pushing a button or speaking
- **Easy to learn:** no training or reminding
- **Efficient:** time to authenticate is short, and time to enroll is at least reasonable
- **Infrequent errors:** low false reject rate
- **Easy recovery from loss:** including latency, convenience, and assured recovery

Deployability

- **Accessible:** physical disabilities and conditions don't prevent use
- **Cost:** negligible per user, or at least plausible for startups with no per-user revenue stream
- **Server compatible:** nothing special required on server/verifier end
- **Browser compatible:** doesn't require (non-standard) plugins
- **Mature:** well tested and fielded beyond research
- **Non-proprietary:** published openly and not encumbered by IP

Schemes to replace passwords

- Password managers
- Proxies
- Federated identity management
- Graphical
- Cognitive
- Paper tokens
- Visual cryptography
- Hardware tokens
- Phone-based
- Biometric

Schemes to replace passwords

[Bonneau et al. 2012]:

- Most schemes do better than passwords on security
- Some schemes do better and some worse on usability
- Every scheme does worse than passwords on deployability
- **Passwords are here to stay, for now**
- Schemes offering some variation of single sign on seem to offer best improvements in security and usability...

Single sign on

- User enrolls with many service providers (SP), shares authentication secrets, e.g. password, with each
  - common scenario: user registers same or predictably modified password with each SP
  - products even exist to automatically synchronize passwords across SPs
    - usability trumps security
- Single sign on: user authenticates **only once** with SSO service, thereafter SSO manages authentication to SPs
  - user has potentially multiple identities with SSO
  - user has potentially multiple identities with SPs
  - SSO trivially can impersonate user

Single sign on

Varieties of SSO: [Pashalidis and Mitchell 2003]

- True SSO: user authenticates to SSO, it **asserts** user's identity to SP
- Pseudo SSO: user authenticates to SSO, it uses SP's own authentication mechanism to authenticate on behalf of user

Pseudo SSO

- User selects identity to authenticate to SSO
- SSO stores user's secrets to authenticate on behalf of user to a particular identity at SP
- Local vs. remote/proxy...

Local pseudo SSO

- SSO service is local to user's machine
  - Typically an encrypted password DB
  - Degree of automation might vary
- Example: password managers
- Since SSO service must present user's secrets to SP, user must trust SSO & local machine with those cleartext secrets

Proxy pseudo SSO

- SSO service is on remote server
  - Typically fully automated, even invisible to user
  - Authentication to SP is redirected (e.g. HTTP 302) to or intercepted by proxy
- Local machine doesn't have access to secrets, but remote service is trusted with cleartext secrets
- Closest example: web browsers with auto-fill and cross-machine synch capabilities

True SSO

- User selects identity to authenticate to SSO
- SSO asserts user's identity to SPs
  - SP is being notified of authentication rather than deciding itself
  - notion of identity might vary between SPs
- Local true SSO: SSO is under physical control of user (less common)
  - could build off of trusted cryptographic co-processor to take control away from user
- Proxy true SSO: external proxy brokers between users and SP
  - Examples: Kerberos, Microsoft Passport

Difficulty of proxy true SSO

- SSO and SPs have a trust relationship, supported by
  - agreement about rights and responsibilities
  - secure communication channel
  - countermeasures to ensure SSO is not compromised
- SSO must define:
  - uniform meaning for attributes used in identities
  - accuracy standard for attributes
  - how to exchange and store secrets
  - obligations of SPs
  - legal instrument for accountability

Upcoming events

- [Wed] A4 due

Humans are…large, expensive to maintain, difficult to manage, and they pollute the environment. It is astonishing that these devices continue to be manufactured and deployed. But they are sufficiently pervasive that we must design our protocols around their limitations.

– Kaufman, Perlman, and Speciner